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Citation for published version:

McIntosh, R, McWhirter, L, Ludwig, L, Carson, AJ & Stone, J 2017, 'Attention and sensation in functional motor disorder', *Neuropsychologia*, vol. 106, pp. 207-215.
<https://doi.org/10.1016/j.neuropsychologia.2017.09.031>

Digital Object Identifier (DOI):

[10.1016/j.neuropsychologia.2017.09.031](https://doi.org/10.1016/j.neuropsychologia.2017.09.031)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Neuropsychologia

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Attention and sensation in functional motor disorder

Robert D McIntosh*¹, Laura McWhirter*², Lea Ludwig³, Alan Carson^{4,5}, Jon Stone⁴

¹Human Cognitive Neuroscience, Psychology, University of Edinburgh, UK

²Royal Edinburgh Hospital, Edinburgh, UK

³University of Hamburg, Germany

⁴Department of Clinical Neurosciences, Western General Hospital, Edinburgh, UK

⁵Department of Rehabilitation Medicine, Astley Ainslie Hospital, Edinburgh, UK

*These authors contributed equally to this work.

Corresponding author:

Dr Robert D McIntosh

Psychology, University of Edinburgh

7 George Square, Edinburgh, EH8 9JZ

Tel: +44 131 6503444

Fax: +44 131 6503461

r.d.mcintosh@ed.ac.uk

Keywords: attention; functional neurology; conversion paralysis; psychogenic; somatosensory; tactile; visual.

Abstract

Functional motor disorder (FMD), also called psychogenic motor disorder or conversion disorder, describes impairments of motor function where there is no evidence of organic disease. The diagnosis is usually confirmed by positive clinical signs, such as Hoover's sign, in which normal power returns when attention is diverted away from the affected limb. This suggests that selective attention is an important determinant of these functional symptoms. The present study is the first specifically to explore the shifting of spatial attention in relation to the side of FMD. We tested 14 patients with unilateral functional upper limb weakness on three tasks requiring detection of visual targets close to the affected or unaffected hand, or touches to the hand itself. Targets were preceded by central cues promoting voluntary shifts of attention, or peripheral cues promoting automatic shifts. We observed a reduced response to visual and/or tactile targets on the affected side in around half of the patients, by comparison with age-matched controls, indicating that some degree of detection cost often accompanies FMD. Additionally, although the patient group showed normal cueing effects on the visual tasks, they had a unilateral absence of cueing effect on the affected side in the tactile task. Consideration of the data in the context of recent theory suggests that the abnormality may be not in the shifting of attention itself, but rather in the *consequences* of attending to the affected side. Specifically, the expected cueing effects may be absent on the affected side, because attention to a functionally weak limb increases the perception of the symptom, including any reduced sensory response. This preliminary research suggests promising new lines of investigation into the role of attention, and particularly somatic attention, in FMD.

Introduction

Functional neurological symptom disorder, also known as conversion disorder, is a condition in which there are one or more symptoms of altered voluntary motor or sensory function, causing distress or impairment, and with clinical findings incompatible with organic disease (American Psychiatric Association, 2013). Functional motor disorder (FMD) is a common reason for referral to neurology clinics, and a common cause of disability in working age adults (Carson et al., 2000, 2011; Stone, Warlow, & Sharpe, 2010). Studies in Scotland suggest that FMD is more common than multiple sclerosis, and that it causes similar levels of disability but with greater psychological comorbidity (Carson et al., 2011; Stone, Carson, et al., 2010).

Clinical tests for FMD often use distraction to reveal normal muscle power, or a change in the frequency or character of a tremor, when the person's attention is drawn elsewhere (Daum, Hubschmid, & Aybek, 2013; Stone & Carson, 2015). For example, one of the most reliable positive features of functional leg weakness is Hoover's sign, in which a weakness of hip extension returns to normal power when attention is drawn away from the affected side, by asking the patient to focus on flexing their other hip against resistance (Ziv, Djaldetti, Zoldan, Avraham, & Melamed, 1998). A cohort study of patients with suspected stroke estimated that Hoover's sign is moderately sensitive (63%) and highly specific (100%) to FMD (McWhirter, Stone, Sandercock, & Whiteley, 2011). These clinical findings are mirrored by experimental work suggesting that automatic aspects of motor control may be preserved in FMD, with impairment evident in more explicit movement tasks in which attention is focused on the action (Pareés et al., 2013).

Abnormal attentional focus has long been thought core to functional neurological disorders, though different ideas about the nature of the abnormality have emerged over time. Janet (1907; as reviewed by Edwards, 2016) believed that such symptoms arose from a

‘retraction of the field of consciousness’, implying a withdrawal of attention from the affected body part. This basic idea, that an insufficiency of attention is responsible for a loss of function, was echoed by later theorists (Ludwig, 1972; Whitlock, 1967), and drew some support from findings of reduced somatosensory evoked potentials in hemianaesthesia (Halliday, 1968; Hernandez-Peon, Chavez-Ibarra, & Aguila-Figueroa, 1963). However, the idea is hard to reconcile with the clinical observation that functional motor symptoms are improved by the diversion of attention elsewhere.

A more recent, and somewhat opposite, proposal is that attention to the affected site or symptom may be a necessary, though not sufficient, condition for FMD and other functional neurological disorders (Edwards, 2016; Edwards, Adams, Brown, Parees, & Friston, 2012). Specifically, focused attention in combination with a strong prior expectation of a symptom, whether positive (e.g. tremor) or negative (e.g. sensory or motor loss), might over-ride normal bottom up signals, causing the expected symptom to become a reality. If the symptom thereby manifests whenever attention is turned to it, the patient might have the subjective impression that it is continuous. Consistent with this, Pareés and colleagues (2012) found that patients with functional tremor, but not those with organic tremor, grossly over-estimate the proportion of time for which their tremor is present. Coding of gaze position in observational video-recordings suggests that patients with functional tremor spend far more time looking at their tremor than do those with organic tremor (~80% vs ~25%) (van Poppelen et al., 2011); and functional imaging suggests that FMD is associated with increased activation of brain areas implicated in self-monitoring (Bell, Oakley, Halligan, & Deeley, 2011; de Lange, Roelofs, & Toni, 2007). It is therefore possible that FMD may be associated with *too much*, rather than too little attention to the affected site.

Surprisingly, given the central role of attention in theories of FMD, there has been very little direct study of attention in such patients. Roelofs, van Galen, Eling, Keijsers, &

Hoogduin (2003) adapted the well-established cueing techniques of Posner (1980) to investigate selective spatial attention in eight patients with FMD of the upper or lower limbs. Visual targets were preceded, at a variable delay, by a predictive central arrow (endogenous cue) or the non-predictive appearance of a box at a potential target position (exogenous cue). FMD patients were overall slower to respond than matched controls, and showed muted effects of endogenous cues at the shortest cue-target delay (150 ms). Patients also failed to show clear *inhibition of return* following exogenous cues at longer cue-target delays (550 ms). Inhibition of return is the transition of cue validity effects, from facilitation at short delays ($< \sim 350$ ms) to inhibition at longer delays ($> \sim 350$ ms). That is, a non-informative exogenous cue initially enhances detection at the cued location, but as the person then reorients away from the cue, detection becomes relatively faster at non-cued locations. This secondary reorienting after an exogenous cue is arguably a *voluntary* process, so an absence of inhibition of return in FMD could be taken as further evidence for impaired voluntary control of attention, with automatic attention relatively preserved (Roelofs, van Galen, Eling, Keijsers, & Hoogduin, 2003).

The focus of the above study was on the distinction between voluntary and automatic shifts of attention. Even so, it is very surprising that no analyses were made of the effect of target side in relation to the side of symptoms. These well-established cueing tasks potentially provide a rich framework for an assessment of asymmetries of attention, toward or away from the affected side, as proposed by several theories of FMD. There are many possible permutations of these tasks, combining different cueing and response methods, and sensory modalities, and we could sample only a subset in the present study. We decided to focus on voluntary and automatic attention to the visual space around an affected or unaffected hand, and on voluntary attention to *tactile* stimulation of the hand. Given that different theories have suggested either under- or over-attention to the affected site, we did not have any strong

a priori commitment to the direction of any asymmetry. Rather, we proposed an initial, exploratory assessment of lateralized visual and tactile detection and attention in patients with unilateral upper limb FMD.

Method

Participants

Patients were recruited from routine neurology or neuropsychiatry outpatient clinics. Patients were between the ages of 18 and 75, and had a diagnosis of functional motor disorder with unilateral upper limb weakness, made by a Neurologist (JS) or Neuropsychiatrist (AC) following DSM-5 criteria (American Psychiatric Association, 2013). Upper limb weakness was self-reported as present continuously. Patients were excluded who had a diagnosis of dementia, learning disability or a comorbid psychiatric disorder, for whom there was any clinical suspicion of factitious disorder, or who did not speak English.

Fourteen FMD patients (8 female, 6 male) took part. Twelve were right-handed by self-report, six of whom had left-sided weakness and six of whom had right-sided weakness. Two were left-handed by self-report, one of whom had left-sided and one of whom had right-sided weakness. The mean age of the FMD group was 39 years (SD 9.9, range 23-53), and the median symptom duration was 3 years and 3 months (range 5 months – 21 years). All patients had positive evidence of functional limb weakness (Daum et al., 2013), and clinical investigations that had shown no signs of organic pathology. Grip strength and tapping frequency were reduced in the affected compared with the unaffected side in all participants. On sensory examination (see Procedure for details), two patients additionally reported reduced sensation in the weak limb (patients FMD01 and FMD02). Patient characteristics, including prescribed medications, are reported in Table 1.

Fourteen healthy control (HC) participants (8 female, 6 male) were recruited from patients' families and from the University of Edinburgh Psychology volunteer panel. Eight were right-handed, five were left-handed and one was 'ambidextrous' by self-report (this participant was considered as left-handed in controlling for hand-dominance at ANOVA). The mean age of the HC group was 40 years (SD 14.0, range: 18-64).

Table 1. Characteristics of the FMD patients. mRS = modified Rankin Scale for disability. Grip strength and tapping rate are reported for weak (W) and strong (S) sides. *No focal deficit or parenchymal MRI brain abnormality at any stage.

Patient	Age /sex	Hand dom	Functional neurological symptoms	Duration	Investigations	Comorbidity	Prescribed medications	mRS (0-6)	Grip (kg) W:S	Taps/ 10 sec W:S
FMD01	48/M	L	L arm weakness L leg weakness L anaesthesia	20 years	MRI brain MRI spine	Hypertension Splenectomy	Amitriptyline Co-codamol Gabapentin Sodium valproate	3	7:34	16:62
FMD02	39/M	R	L arm weakness R leg weakness Intermittent dysarthria	5 years	MRI brain. MRI spine	none	Trazodone	3	0:48	0:71
FMD03	41/F	R	L arm weakness L leg weakness	5 months	MRI brain	R trigeminal neuralgia	Carbamazepine Dihydrocodeine Gabapentin Paracetamol	3	10:31	30:48
FMD04	41/F	R	L arm and hand weakness	2 years	MRI wrist X-ray wrist	none	None	1	12:31	54:61
FMD05	23/F	R	R arm weakness	1 year	MRI brain MRI cervical spine	none	None	4	5:28	39:54
FMD06	25/F	R	R arm weakness R leg weakness Dissociative seizures	1 year	MRI brain. MRI spine	Migraine	Cyclizine Dihydrocodeine Topiramate Tramadol	3	20:26	46:49
FMD07	31/F	R	R arm weakness R leg weakness	1 year	MRI brain MRI lumbar spine	Irritable bowel syndrome Mild depression	Mirtazapine	1	25:29	57:59
FMD08	53/M	R	L arm weakness L leg weakness	6 years	MRI brain MRI cervical spine	Obstructive sleep apnoea Restless leg	Diazepam Rabeprazole Ropinirole	4	12:24	26:33

							Sertraline Tramadol Trazodone			
FMD09	24/M	R	R arm and hand weakness	2 years	MRI shoulder and brachial plexus Neurophysiology	none	None	2	17:29	53:61
FMD10	52/M	R	R leg weakness Dissociative blackouts	5 years	MRI brain	Subarachnoid haemorrhage (3 years prior)*	Sertraline	N/A	N/A	N/A
FMD11	34/M	L	R arm weakness R leg weakness	21 years	MRI brain. MRI spine	none	Ibuprofen Omeprazole Paracetamol	3	23:41	58:60
FMD12	40/F	R	R arm weakness R leg weakness R facial anaesthesia	10 years	MRI brain MRI cervical spine	none	Amitriptyline Co-codamol Omeprazole	4	14:29	11:55
FMD13	48/F	R	L arm weakness L leg weakness Dissociative seizures	2 years	MRI brain	none	Citalopram Duloxetine Topiramate	4	12:30	28:39
FMD14	41/F	R	L arm weakness L leg weakness Functional dizziness	7 years	MRI brain MRI spine	none	Citalopram Propranolol	N/A	18:22	23:44

Procedure

This study was conducted with approval from the relevant NHS Research Ethics Committee and the University of Edinburgh Psychology Research Ethics Committee, and written informed consent was obtained for each participant.

Each participant attended the University of Edinburgh Visuomotor Laboratory once. For patients, not controls, the attention tasks were preceded by assessment of maximum tapping rate (best of three ten second trials), hand dynamometer grip strength (best of three attempts), and tactile sensation. Sensation was tested using a standard neurological examination, with light touch and pinprick (neurotic) stimulation of upper limbs, including hands (stimulation of each dermatome). All participants then performed three cued target detection tasks to assess: visual exogenous attention (vX task); visual endogenous attention (vN task); and tactile endogenous attention (tN task). The vX and vN tasks were performed first, with the order alternated between participants within each group; the tN task was performed last.

Each task was performed on a widescreen monitor (active display 530 x 298 mm; resolution 1920 x 1080; refresh rate 60 Hz), tilted backwards by $\sim 70^\circ$ so that it faced up from the table toward the participant, at a viewing distance of ~ 60 cm. A schematic diagram of example stimulus displays is shown in Figure 1. The participant sat with their hands resting palm-down on the screen surface, with each index fingertip abutting a white outline box (35 mm square), which acted as a placeholder for visual targets. These boxes were centred 134 mm to left and right of a white outline diamond (17 mm side length), which had a 1 mm white fixation point at its centre, coinciding with the horizontal centre of the screen. In the tactile task, the participant had a mechanical ‘tapper’ attached by medical tape to the medial side of the distal phalanx of the each index finger. This device housed a 12 V solenoid that drove a plastic rod with a blunt conical tip to touch the skin whenever a current passed

through the solenoid (Heijo Research Electronics, UK). All tasks were performed in a quiet room with dim ambient illumination. The tactile task was performed with continuous ambient white noise, sufficient to mask any sound from the tapper.

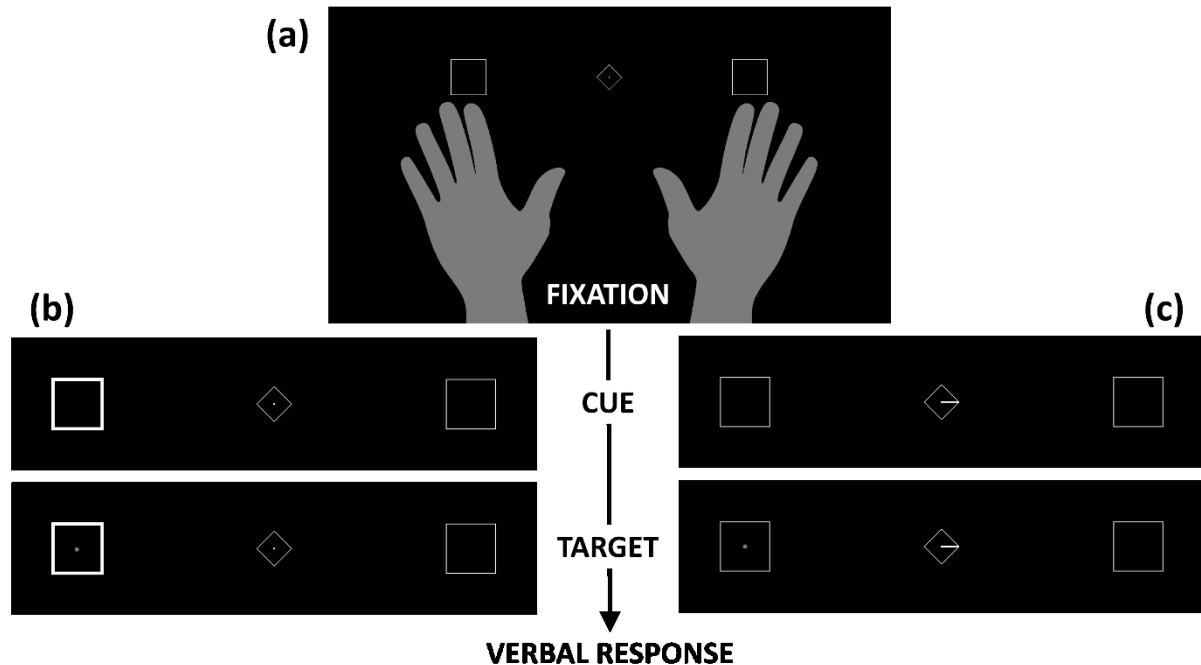


Figure 1. Schematic diagram of example stimulus displays. **(a)** Fixation display for all tasks, with the positions of the hands indicated (these were not part of the display). **(b)** Cue and target displays for a validly cued left target trial in the exogenous task. **(c)** Cue and target displays for an invalidly cued left target trial in the endogenous visual task. The endogenous tactile task had identical cues to the visual task, but the target stimulus was a tap to the distal phalanx of the index finger. See the main text for full task details.

Each trial began with a 330 ms sequence in which four white points converged from the corners of the central diamond to meet at its centre. This dynamic display was included to orient attention to the central fixation point at the beginning of each trial, and was followed by a static fixation period, which varied randomly between 170-1170 ms, prior to the onset of a visual cue. The cue was followed by the onset of a target after a variable delay between cue and target onset (cue-target-onset asynchrony: CTOA). In the visual tasks, the target was a 2.8 mm diameter mid-level grey dot in the centre of one of the boxes; in the tactile task, the target was a single tap, with the rod tip remaining in skin contact until the end of trial. The participant was instructed to respond as quickly as possible to the presentation of the target

by saying ‘Ta’. Reaction time was recorded via an individually calibrated voice-activated switch. Each trial ended as soon as a response was made, or if no response was detected within 2000 ms.

In the visual exogenous (vX) task, the cue was a ‘brightening’ of one of the two boxes, achieved by increasing the thickness of the box outline from 2 pixels (~0.6 mm) to 8 (~2.2 mm). This was followed by the target after a short (150 ms) or long (550 ms) CTOA, except in catch trials, in which no target appeared. Catch trials were included to discourage and detect anticipatory responding. For trials in which a target appeared, the cue was equally often valid (same side as target) as invalid (opposite side to target), so that the cue had no overall predictive value. The participant was made aware of this fact, and advised to ignore the cues. There were 16 trials for each combination of target side (left, right), cue validity (valid, invalid) and CTOA (150, 550), mixed randomly with 16 left cue and 16 right cue catch trials, for a total of 160 trials, across two blocks of 80.

In the visual endogenous (vN) task, the cue was a white line joining the central dot to the right or left hand corner of the fixation diamond, thus ‘pointing’ to the left or right. This was followed by the target after a 550 ms CTOA, except in catch trials with no target. The cue validly predicted the target location on 75% of trials in which a target appeared. The participant was made aware of this fact, and advised to take notice of the cue direction. There were 48 valid trials and 16 invalid trials per target side (left, right), mixed randomly with 16 left cue and 16 right cue catch trials, for a total of 160 trials, across two blocks of 80.

The tactile endogenous (tN) task was identical to the vN task, except that the target was a tactile rather than a visual event.

Data processing

First, void trials were excluded. These were trials in which a vocal response heard by the experimenter was not detected by the voice-activated switch (or, rarely, in which the switch was triggered by a noise that was not a response). The median number of void trials for FMD patients was 2 (range 0-43) for the vX task, 3.5 (range 0-35) for the vN task and 0 (range 0-3) for the vT task. For controls, the median number was 1 (range 0-5) for the vX task, 1 (range 0-6) for the vN task and 0 (range 0-4) for the vT task. Void trials were rather more common for patients than for controls, as controls tended to maintain a more consistent vocal force. This difference was not apparent in the vT task, probably because the ambient white noise encouraged louder vocalisation.

Second, false alarms and anticipations were excluded. False alarms are target-present responses made on catch trials, and anticipations are target-present responses made prior to or within 100 ms of target onset on non-catch trials. Most participants had acceptably low rates of false alarms (vX task <3%; vN task <6%; tN task <9%) and anticipations (vX task <2%; vN task <1%; tN task <4%). However, patient FMD01 had extremely high rates of false alarms, responding on 100% of catch trials when a peripheral cue appeared on the unaffected (right) side and on 50% of trials when it appeared on the affected (left) side; this was mirrored by high rates of anticipations on target-present trials (39% when cued to the unaffected side; 13% when cued to the affected side). This tendency was also observed, albeit less severely, in one control participant, who showed false alarm rates of 13% and 25%, and anticipation rates of 13% and 25%, when cued to left and right respectively. Given their clear tendency to respond to the exogenous cues, rather than waiting for a target, these two participants were excluded from subsequent analyses of RT for the vX task.

Third, the hit rate (correct responses to the target) was calculated for each participant for each condition, with lower values thus representing a higher miss rate (i.e. failures to

detect the target). Miss trials were then excluded from subsequent analysis. Finally, reaction time (RT) on hit trials was subjected to a two-stage analysis, surveying lateralized responding at the individual level and then analysing group-level results across the cueing conditions for each task. These analysis steps will be detailed in the presentation of Results.

Results

Hit rate by target side

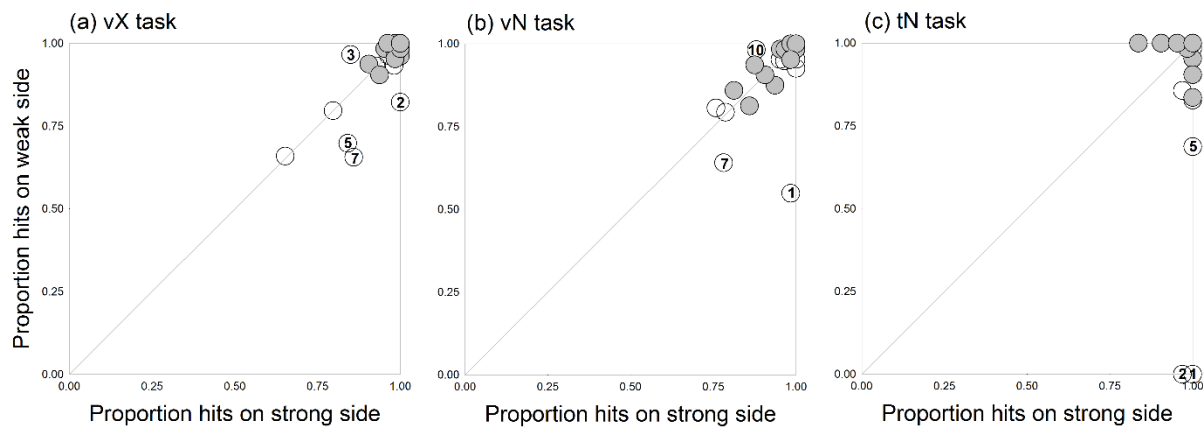


Figure 2. Proportion of hits on each side for patients (open circles) and controls (grey circles) in each task. In each panel, each control is plotted twice, in mirror symmetrical positions around the diagonal of equal hit rates (i.e. once with left side coded as weak, and once with right side coded as weak). Numbers indicate study codes for patients with significantly asymmetrical performance by comparison to controls.

Figure 2 shows the proportion of hits for targets on each side for each participant in each task. For patients, the data are coded to reflect ‘weak’ and ‘strong’ sides (i.e. ipsilateral and contralateral to the FMD). Because controls do not have a weak and strong side, each control point is plotted twice, in mirror-image positions around the diagonal of equal hit rates (i.e. once with left weak and right strong, and again with left strong and right weak). In each task, at least some FMD patients had abnormally low hit rates on one or both sides. Because our main interest was in asymmetries, a normal cut-off for the absolute difference in hit rates between sides was calculated for each task. To calculate these cut-offs, we used the modified t-method recommended by Crawford & Howell (1998). The distribution of control asymmetries was non-normal for all tasks (Shapiro-Wilks test $W < 0.77$, $p < 0.005$), so we adopted a conservative alpha criterion of 0.02, as recommended by Crawford, Garthwaite, Azzalini, Howell, & Laws (2006). This was further divided by the number of patients tested

on each task ($n = 14$), to protect against Type I errors. The resultant alpha criterion (0.0014) was applied, one-tailed (because the test is on the absolute magnitude of asymmetry), to calculate a critical t value and thereby define the cut-off for abnormal asymmetry. Patients exceeding this cut-off are identified by their study numbers in Figure 2.

Two patients (FMD01, FMD02) did not detect any targets on the weak side in the tN task. These two patients had both shown functional hemianaesthesia on clinical testing, so failure to detect targets on the affected side is consistent with this. Of the remaining eight instances of an asymmetrical hit rate, the six largest asymmetries reflected a disadvantage for the weak side, with two smaller asymmetries indicating a disadvantage for the strong side. Asymmetrical hit rates were thus associated chiefly with a disadvantage for the weak side.

Reaction Time (RT)

As noted in Methods, patient FMD01 and one control participant were excluded from the analysis of RT for the vX task, due to high rates of false alarms and anticipations. In addition, patients FMD01 and FMD02 were excluded from the analysis of RT for the tN task, as they never detected a tactile target on the weak side. For the remaining participants, median RT was taken as a robust measure of central tendency for each condition. The analysis of RT then proceeded in two stages. First, the individual performances of RT, collapsed by target side, were screened for evidence of overall asymmetries in RT; group level ANOVAs were then performed to study the effect of attentional cueing for targets on each side.

RT by target side

Figure 3 shows the median RT (mean of medians across cue conditions) for targets on each side for each participant in each of the tasks. Each control point has again been plotted twice, in mirror-image positions around the diagonal of equal hit rates. One-tailed cut-offs for the absolute difference in hit rates between sides were calculated by the same methods as described for hit rate, above (Crawford & Howell, 1998; Crawford et al., 2006). The distribution of asymmetries was judged to be non-normal for vN and tN tasks only (Shapiro-Wilks $W < 0.87$, $p < 0.05$), but a conservative alpha criterion of 0.02 was adopted for consistency across all three tasks, and further divided by the number of patients included per task ($n = 13$, 14 and 12 for vX, vN and tN tasks respectively). Patients exceeding the cut-off for abnormal asymmetry in each task are identified by study numbers in Figure 3.

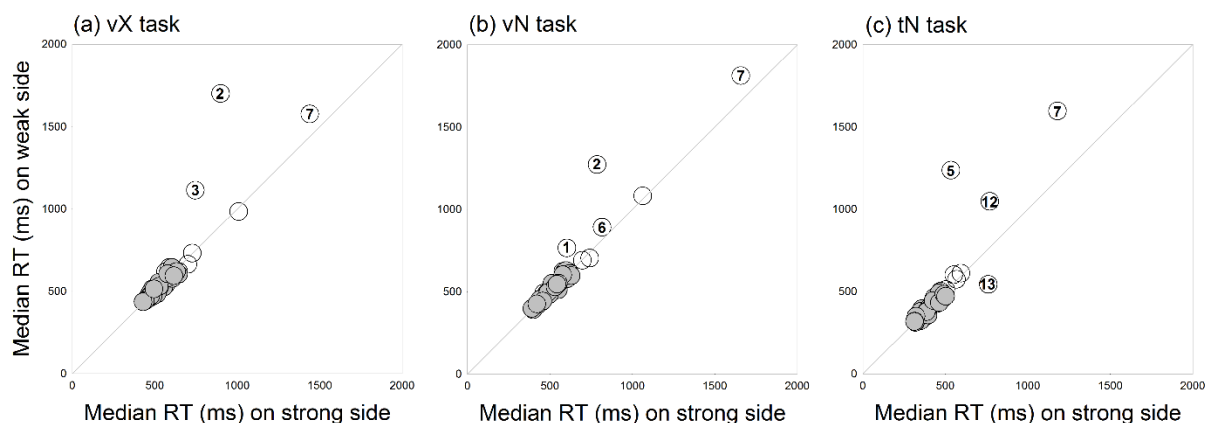


Figure 3. Median Reaction Time (RT) on strong side and weak side for patients (open circles) and controls (grey circles) in each task. In each panel, each control is plotted twice, in mirror symmetrical positions around the diagonal of equal hit rates (i.e. once with left side coded as weak, and once with right side coded as weak). Numbers indicate study codes for patients with significantly asymmetrical performance by comparison to controls.

The most striking aspect of Figure 3 is that the FMD patients were, in general, slow to respond in all tasks. The median RTs for controls clustered around or below 500 ms, but several patients took two to three times as long to respond. Across tasks, there were 11

instances of asymmetric RTs beyond normal limits. Most of these asymmetries arose in the context of an overall slowing (i.e. high RTs on both axes in Figure 3). Given that higher RTs are likely to be associated with greater uncertainty of estimation, one might well expect more asymmetries to appear by chance as RTs increase, and so the identification of asymmetry in any single patient must be somewhat uncertain. Nonetheless, the pattern across patients is anything but random: of the 11 instances of asymmetry across tasks, ten reflected slower detection for targets on the weak side. Note that the four patients who had low *hit rates* on the weak side (Figure 2) also showed inflated median RTs on this side (Figure 3) (patients FMD01, FMD02, FMD05 and FMD07).

RT by cueing condition

Group-level analyses were performed on the \log_{10} transformed median RT for each condition, to moderate the impact of outlying values, and to meet the assumptions of ANOVA.

Transformed RTs were submitted to mixed-model ANOVAs with the between-subjects factor of group (FMD, HC) and the within-subjects factors of target side (weak, strong) and cue validity (valid, invalid), with the additional factor of CTOA (150, 550) for the vX task. For HC participants, the left side was arbitrarily coded as the weak side; this produced an approximate match whereby the weak side was ipsilateral to the dominant hand for 7/14 patients and for 6/14 controls.

Group mean results for the **vX task** are shown in Figure 4. The FMD group were overall slower than the HC group [$F_{1,24}=13.7$, $p < 0.005$, partial $\eta^2 = 0.36$]. The effect of group did not interact significantly with target side [$F_{1,24}=2.5$, $p = 0.13$, partial $\eta^2 = 0.09$], despite the instances of asymmetry in individual FMD patients (Figure 3a) There was a main effect of CTOA, with faster responses at the longer delay [$F_{1,24}=15.3$, $p < 0.001$, partial $\eta^2 = 0.39$]. The expected main effect of cue validity was confirmed, with relatively faster

responses to validly cued targets [$F_{1,24}=9.3$, $p < 0.01$, partial $\eta^2 = 0.28$]. This cueing effect interacted significantly with CTOA [$F_{1,24}=10.1$, $p < 0.005$, partial $\eta^2 = 0.30$], being smaller at the longer CTOA. However, although the facilitatory effect of endogenous cueing decreased with CTOA, the effect did not reverse at the longer CTOA, for either group. An even longer CTOA might have thus been required for inhibition of return to emerge in this particular task. Overall, despite their generalised slowing, the FMD group had a broadly normal pattern of exogenous visual attention.

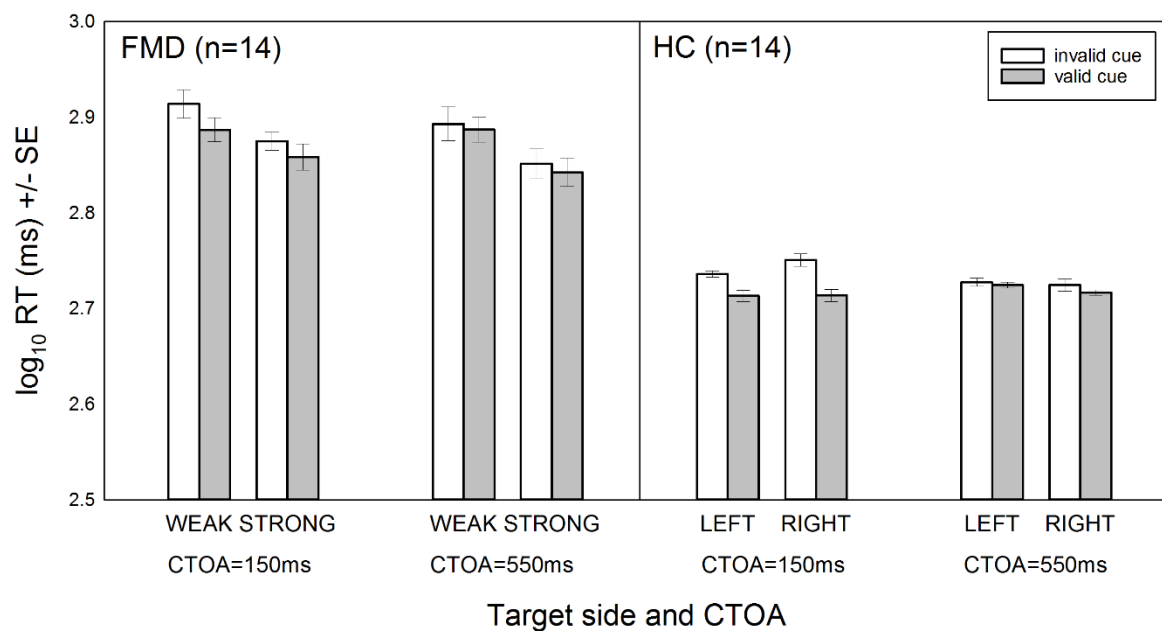


Figure 4. Transformed reaction times (\log_{10} RT) by target side, cue-target onset asynchrony (CTOA), and cue validity, for patient (FMS) and control (HC) groups in the visual exogenous (vX) task; error bars depict standard errors for within-subjects designs (Cousineau, 2005, with correction suggested by Morey, 2008).

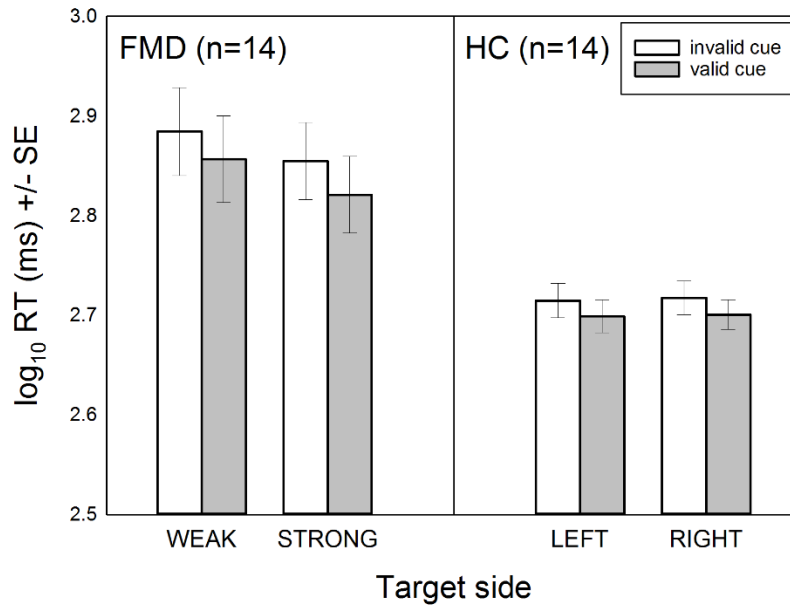


Figure 5. Transformed reaction times (\log_{10} RT) by target side and cue validity for patient (FMS) and control (HC) groups in the visual endogenous (vN) task; error bars depict standard errors for within-subjects designs (Cousineau, 2005, with correction suggested by Morey, 2008).

Group mean results for the **vN task** are shown in Figure 5. The FMD group were slower than the HC group [$F_{1,26}=11.4$, $p < 0.002$, partial $\eta^2 = 0.31$], and a significant interaction with target side confirmed that they were especially slow to respond to targets on the weak side [$F_{1,26}=4.5$, $p < 0.05$, partial $\eta^2 = 0.15$]. The expected effect of cue validity was obtained, with relatively slower responses to invalidly cued targets [$F_{1,26}=36.5$, $p < 0.001$, partial $\eta^2 = 0.58$], and no other effects were significant. Thus, the FMD group were slow to respond, especially to the weak side, but had normal endogenous cueing effects.

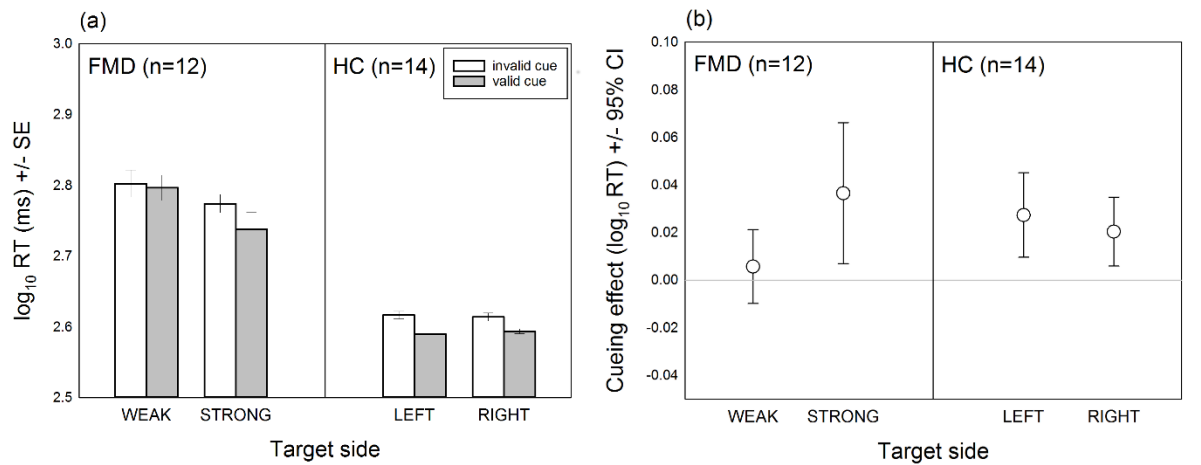


Figure 6. (a) Transformed reaction times (\log_{10} RT) by target side and cue validity for patient (FMS) and control (HC) groups in the tactile endogenous (tN) task; error bars depict standard errors for within-subjects designs (Cousineau, 2005, with correction suggested by Morey, 2008). **(b)** Cueing effect (invalid – valid) by target side for each group; error bars depict 95% confidence intervals.

Group mean results for the **vT task** are shown in Figure 6a. Again, the FMD group were significantly slower than controls [$F_{1,24}=14.1$, $p < 0.005$, partial $\eta^2 = 0.37$]. However, the main effect of cue validity [$F_{1,24}=23.5$, $p < 0.001$, partial $\eta^2 = 0.49$] was modified by an interaction with group and target side [$F_{1,24}=4.6$, $p < 0.05$, partial $\eta^2 = 0.16$], indicating a differential reduction of the cueing effect for tactile targets on the weak side in the FMD group. The cueing effect (subtraction of valid from invalid RT) was significantly different from zero on both sides of space for the HC group, but on the strong side only for FMD patients (Figure 6b). Endogenous cueing thus had a normal influence for targets on the unaffected side, but apparently failed to modulate detection of touches to the weak limb. The implications of this result will be the focus of later discussion.

Discussion

The most salient - not the most interesting - pattern in the present study was a global slowing of target detection in upper-limb FMD, whether targets were presented visually or delivered by touch. Generalised slowing was similarly evident in Roelofs, van Galen, Eling, Keijsers, & Hoogduin's (2003) experiment, which used vocal, manual or pedal responding for target discrimination. However, most of the present patients were on a variety of antidepressant, anti-epileptic and/or analgesic medications (see Table 1), which could cause fatigue and drowsiness, so no specific neuropsychological account of psychomotor slowing is necessarily warranted (e.g. Hindmarch, Kerr, & Sherwood, 1991; Levine & Sice, 1976). Our focus is instead on possible asymmetries in relation to the side of functional motor weakness. This is the first study to explore this issue, despite the prominence of attention as an explanatory concept in the field of functional neurological disorders.

Individual asymmetries of RT, and/or rate of missed targets, were common amongst FMD patients, and were overwhelmingly associated with poorer performance on the side of motor weakness. This disadvantage for detection of targets on the weak side was seen in at least one of the three tasks in half of the FMD group. Two patients (FMD01 and FMD02) failed to detect a single tactile target on the weak side; in these cases, the failure was consistent with the clinical picture of functional hemi-anaesthesia associated with the motor weakness. Interestingly, both of these patients also showed a disadvantage for the affected side in at least one of the two *visual* tasks. Impaired detection on the weak side is thus common, though far from universal, in upper limb FMD, and can affect vision as well as touch. Because we always presented visual targets close to the impaired hand, we are unable to say whether the visual effects are specific to stimuli in the near peripersonal space around the body, or would apply also to visual stimuli further from the body. This would be an interesting question for further research.

These detection tests have exposed a reduced responsiveness to tactile and/or visual events on the side of functional weakness, which – in most cases – was not an obvious part of the clinical presentation. A factitious origin seems unlikely, because a deliberate attempt to feign numbness would not be expected to show in sub-second differences in reaction times, and would seem more likely to be specific to tactile stimulation of the hand, rather than affecting visual stimulation of the near peripersonal space around it. At the same time, reduced responsiveness on the weak side is not wholly unexpected, since functional motor and sensory symptoms often co-occur within a generalised loss of function (Stone, Warlow, & Sharpe, 2010). This may reflect a fuzzy separation of sensation and movement in folk beliefs about the body, so that weakness and numbness are part of the same expectation of disability. However, impaired sensory detection on the weak side does not itself offer any insight into the possible role of attention. It could be compatible with the classical idea of a withdrawal of attention from the affected site (Janet, 1907; Ludwig, 1972; Whitlock, 1967), or with the more nuanced idea that attention to the affected site precipitates and maintains functional symptoms (Edwards, 2016; Edwards, Adams, Brown, Pareés, & Friston, 2012). To assess the role of attention, we should examine the modulation of reaction times by pre-cueing.

On both of the *visual* tasks, cueing effects were broadly normal, whether the cue was exogenous (peripheral brightening) or endogenous (central symbolic). Thus, our visual tasks did not support Roelofs and colleagues' (2003) conclusion that voluntary attentional shifting is impaired in FMD. However, our data are not in direct conflict with that earlier study either. First, the impairment reported by Roelofs and colleagues for an endogenous task was a muted cueing effect at the shortest CTOA (150 ms); but our endogenous task did not include such a short CTOA, because we chose cues that were most likely to be effective, in order to expose any possible asymmetries. Second, in their exogenous task, Roelofs and colleagues found that

their patient group did not show inhibition of return at the longest CTOA. In the present study, neither patients nor controls showed clear inhibition of return on the timescale tested, so the patients were not abnormal in this respect. Third, the abnormalities reported by Roloefs and colleagues (2003) were quite subtle, so it is not unlikely that we might not replicate them, especially considering that FMD samples tend to be modest ($n=8$ in the earlier study; $n=14$ in the present). However, even if we had replicated a slowing of voluntary attention in FMD, we might have questioned its theoretical relevance in the absence of any differential relation to the side of symptoms, especially considering the global psychomotor slowing already discussed.

The *tactile* task, with endogenous visual cueing, presented a more interesting pattern. FMD patients showed a specific absence of cueing effect when targets were presented to the weak limb, with a robust cueing effect for touches to the unaffected hand. On first consideration, this seems to support the idea that patients have difficulty shifting attention to the affected side. On closer inspection, however, this interpretation may be less compelling. The cueing effect on each side reflects the additive combination of a reaction time benefit for validly-cued targets *and* a reaction time cost for invalidly-cued targets, both of which derive from the voluntary shifting of attention to the cued location prior to target appearance. A failure to shift attention to the weak side when cued would eliminate the validity benefit for targets on that side, but it should also reduce the invalidity cost for targets on the opposite side, and would thus be expected to limit the total cueing effect on both sides of space. The specific *elimination* of cueing effect for targets on the side of motor weakness is therefore not necessarily strong evidence of a specific inability to shift attention to that side; as noted earlier, it would also be hard to reconcile with the established clinical wisdom that drawing attention to the affected site exacerbates the expression of functional symptoms.

An alternative interpretation, more compatible with clinical wisdom, can also be considered. According to Edwards et al. (2012; see also Edwards, 2016), functional symptoms are maintained by attention to the affected site, because focused attention heightens the expectation of that symptom, allowing the expectation to dominate the bottom-up evidence. If the expectation of weakness includes the notion of numbness, then cueing to the affected hand could heighten this expectation of numbness, rendering patients less responsive to touches on that hand. To the extent that this effect operates, across patients, the normal cueing benefit would be reduced or absent (or, in extreme instances, could even be reversed). By contrast, for targets on the unaffected hand, the consequences of cueing would be exactly as normal. The specific abnormality observed in the tactile task may thus fit most closely with the hypothesis of functional symptoms advanced by Edwards and colleagues (2012). By this interpretation, the allocation of attention in response to cueing is normal in FMD, but the *consequences* of attentional allocation differ depending upon whether the target is then presented to the affected or unaffected side.

The model considered above is not specific to functional motor symptoms, but was proposed as a framework to encompass a range of functional motor and sensory symptoms (Edwards et al., 2012). Its logic has recently been extended even more widely across the range of functional disorders (Van den Bergh, Witthöft, Petersen, & Brown, 2017). The general idea is that prior expectations of certain symptoms or sensations come to dominate direct sensory evidence and to determine the patient's experience, making these expectations a self-fulfilling prophecy. Focused attention plays a key role by sharpening the precision of these predictions, thereby increasing their power to over-rule sensory evidence. In the present study, we suggest that attention may be shifted normally toward a limb with functional weakness, but has the paradoxical consequence of reducing responsiveness to sensation from the limb. This might be analogous to the classic Hoover's sign, whereby functional motor

symptoms are exacerbated by attention to the affected limb, and ameliorated by distraction away from it (Daum, Hubschmid, & Aybek, 2013; Stone & Carson, 2015). Admittedly, the analogy in our results is only partial: the loss of the normal cueing effect for weak side tactile targets is directionally consistent with a relative benefit of invalid cueing, but it falls short of a reversal of cueing effects that would completely mirror Hoover's sign.

Of course, the present study was somewhat exploratory, and we must be circumspect about building theoretical inferences upon one significant three way interaction ($p < 0.05$) in a relatively modest sample of patients. The absence of cueing effect for tactile targets on an affected limb requires replication, as does our broader suggestion that attentional shifting itself may be normal in patients with FMD, particularly as this contrasts with the conclusions of Roelofs and colleagues (2003). Our study was necessarily limited in the range of experimental conditions that could be sampled. We did not have scope to include a neutral cue condition (a non-directional warning of an impending target) to disambiguate the costs and benefits of different cue-target combinations relative to a common baseline; this would be a valuable addition for future work. The data suggest further potentially fruitful avenues. For example, our main finding of interest came from the tactile task, which used endogenous visual cueing. If shifting attention to the affected site reduces responsiveness to sensation from the limb, then a similar pattern of reaction times should be obtained, regardless of whether attention is cued endogenously or exogenously (e.g. by brightening the space immediately around the hand). Somatosensory evoked potentials might also be reduced for validly-cued touches to the affected side in FMD patients. Evoked potentials would also have the power to discriminate cue-locked from target-locked components, discriminating more cleanly between the orienting of attention and its consequences for target processing. Furthermore, it would be interesting to follow up the hints that FMD may affect visual and not just somatosensory detection, and to test whether this is modulated by visual proximity to

the affected body site. These methods might be adapted to test patients with more diverse functional conditions, as contemporary theories suggest that focused attention should gate the expression of a wide range of functional symptoms (Edwards et al., 2012; Van den Bergh et al., 2017).

In summary, this study is the first to assess the shifting of spatial attention in relation to the side of symptoms in patients with FMD. Our data do not support an earlier claim for a general impairment of endogenous attention in FMD (Roelofs et al., 2003), and nor do they show any *unambiguous* abnormality of attention shifting. However, we did observe a reduction in tactile and visual detection on and around the affected limb in at least some patients. Even more interestingly, we found an apparent absence of normal cueing effects for touches on the affected hand, which may be most compatible with the hypothesis that attention is a critical factor gating the expression of functional neurological symptoms (Edwards, 2016; Edwards et al., 2012). If so, the observed abnormality may not be in the shifting of attention itself, but rather in the *consequences* of attending to the affected site. Our findings require replication and elaboration, and our interpretation is tentative. However, this preliminary research suggests promising new lines of investigation into the role of attention, and particularly somatic attention, in functional motor disorders

Acknowledgements

Laura McWhiter received partial funding from the Royal College of Psychiatry, Lea Ludwig was supported by an Eraumus Scholarship, and Jon Stone was supported by a NRS Career Fellowship from NHS Scotland. The authors are grateful to the patient and control participants, to Ronnie Wiegand and Elena Gherri for technical help and advice, and to Elena Gherri and Ingrid Hoeritzauer for critical comments on an earlier draft of this manuscript.

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